RICH Detector for the EIC's Forward Region Particle Identification

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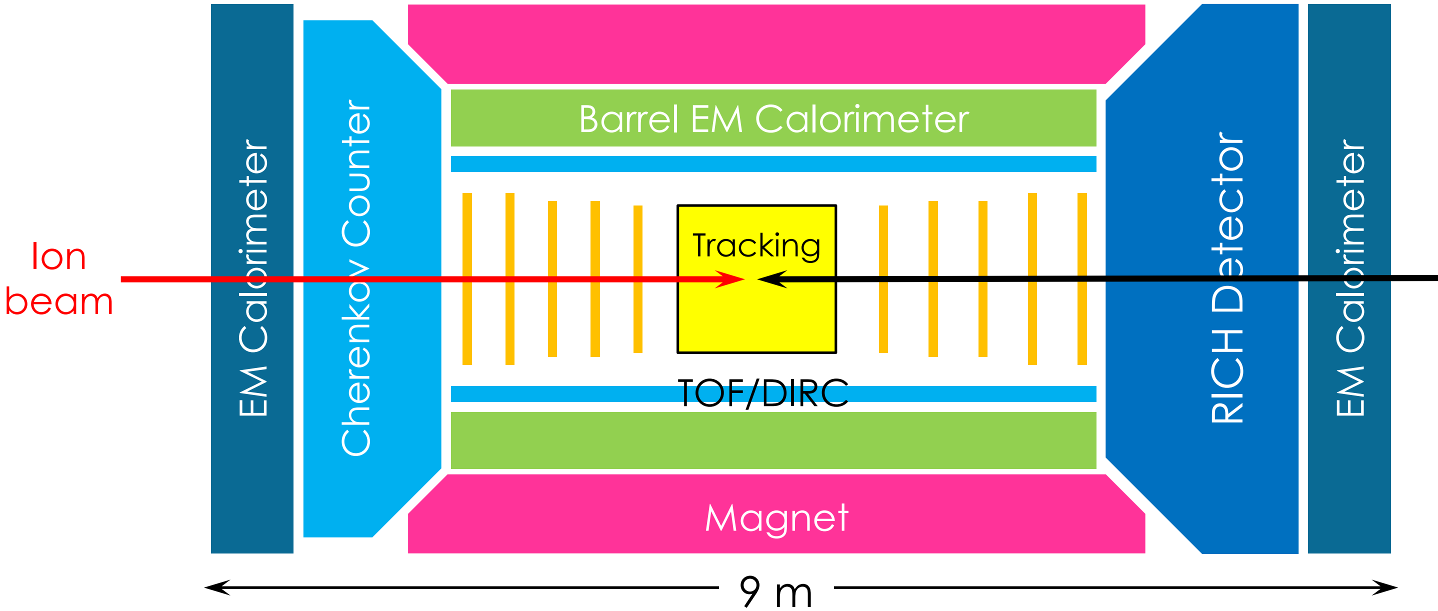
an EIC R&D Proposal – Jan 13, 2014

Overview

- Motivation
- Detector Concepts and Key Technologies
  - Dual radiator RICH
  - Modular RICH
  - Aerogel
  - MCP-based LAPPD
  - GEM-based readout
- Proposed RICH R&D Project
  - Tasks and milestones
  - Budget
- Summary

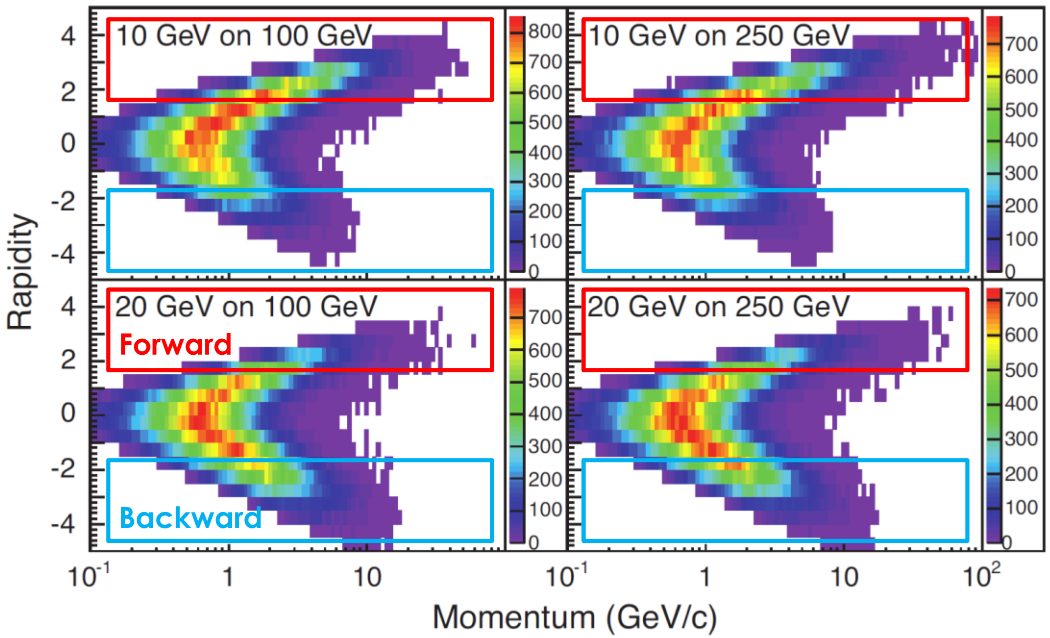
EIC PID Requirements

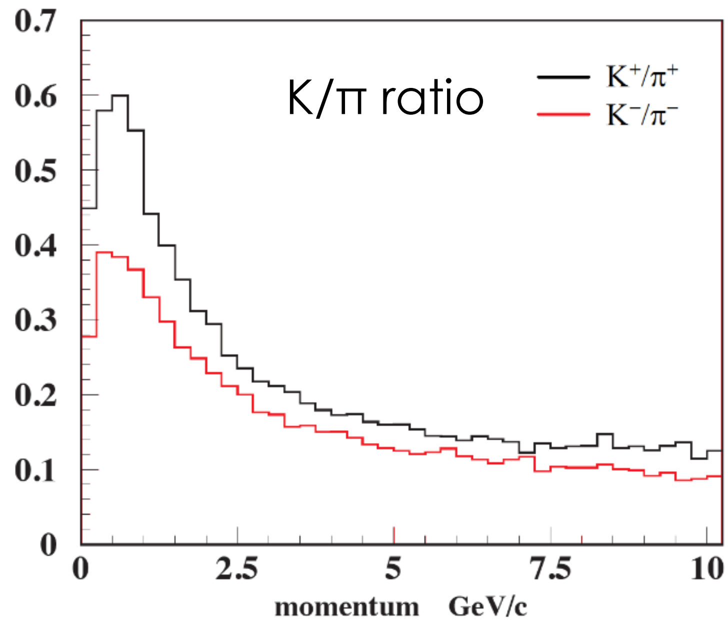
- Very rich physics program:
  - Nucleon tomography and spin structure
  - Quark hadronization
  - Spectroscopy
  - Many more …
- Dedicated EIC machine and spectrometer
  - Hermetic detector system
  - Large momentum range
  - Multi-particle detection in final states



Hadron Identification in SIDIS

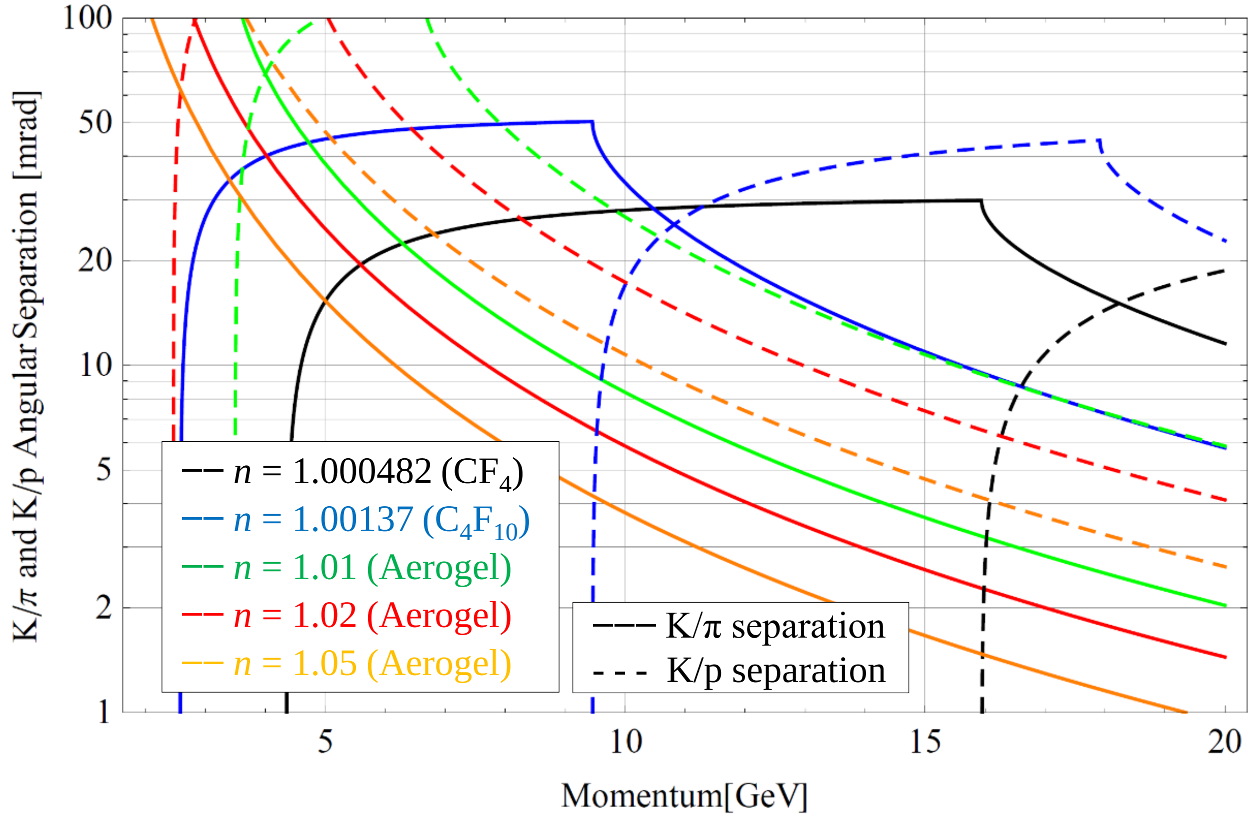
- Semi-Inclusive Deep-Inelastic Scattering (SIDIS)
  - Golden channel to study spin-orbital correlation through transverse momentum-dependent parton distributions (TMDs)
- K/π identification in Forward(Backward) region:
  - 0 – 15 GeV, 4-σ separation





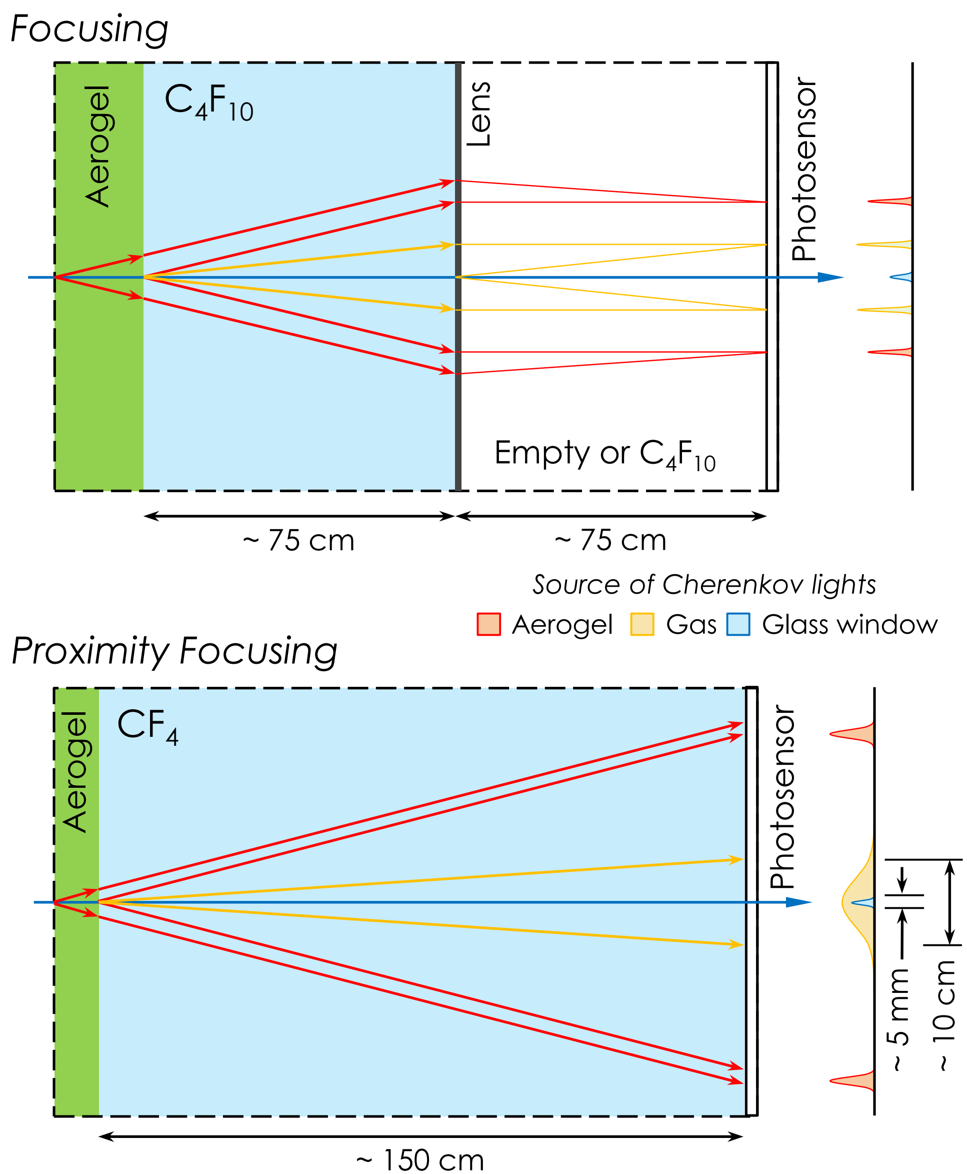
Choice of Technologies

- Multiple technologies are needed
- 0 – 5 GeV: Time-of-flight
- 5 – 10 GeV: Aerogel RICH (Used in HERMES, LHCb, AMS, BELLE …)
- 10 – 15 GeV: heavy gas
  - C_4F_{10}/C_4F_8O RICH
    - Good light yield
  - CF_4 threshold counter
    - Need Aerogel RICH to veto protons
    - Can cover much higher range as RICH



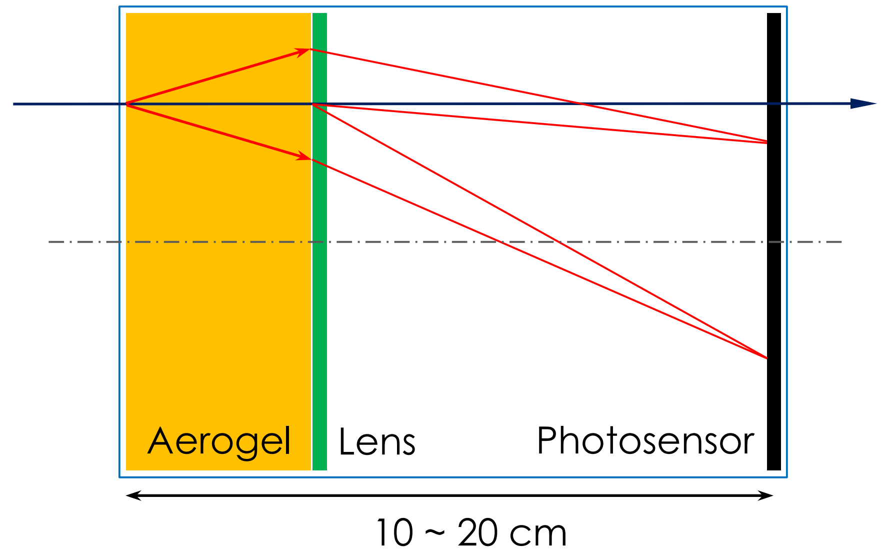
Dual Radiator Concept

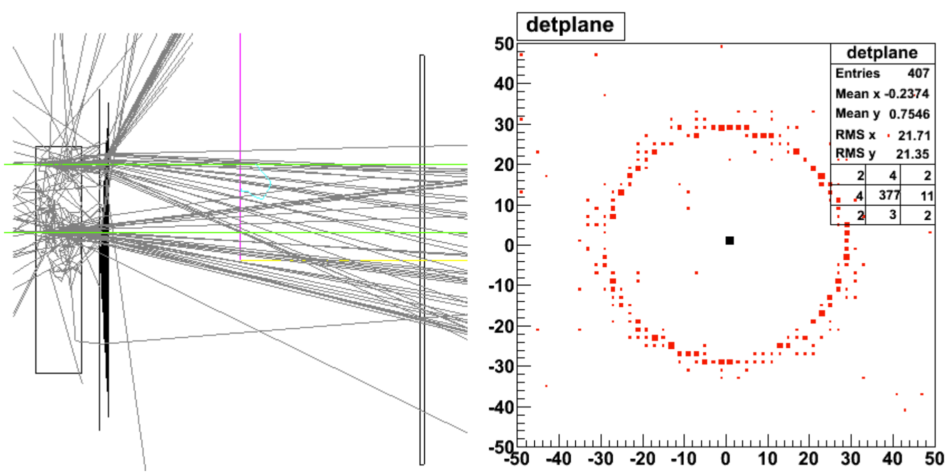
- General geometry constraint: ~150 cm length
- Focusing RICH
  - Aerogel RICH: 3 – 10 GeV
  - C_4F_{10}: 10 – 20 GeV
  - Focused by a Fresnel lens
  - Readout resolution: < 2 mm
- Proximity Focusing
  - Aerogel RICH: 3 – 10 GeV
  - CF_4 threshold counter: 8 – 17 GeV
    - Signals from readout window will be mixed with photons from CF_4
  - Readout resolution: < 4 mm



Modular Concept

- Modular design for maximum flexibility
  - Very compact design, size of a shoe box
  - Can be tiled to cover different geometries, used in various experiments
- Focusing aerogel RICH
  - Covers 3 – 10 GeV
  - Needs to be paired with additional gas RICH detector
  - Focusing Fresnel lens
    - Concentric rings for parallel tracks
  - Readout resolution: < 0.5 mm

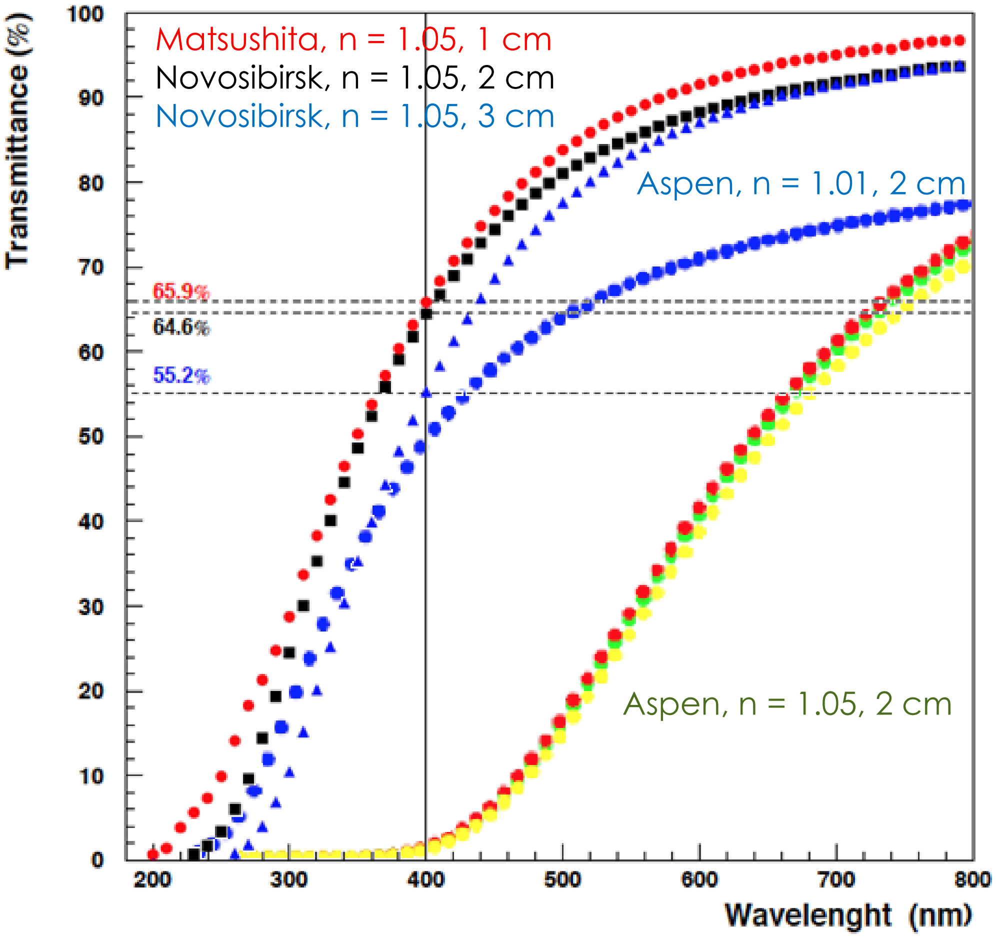




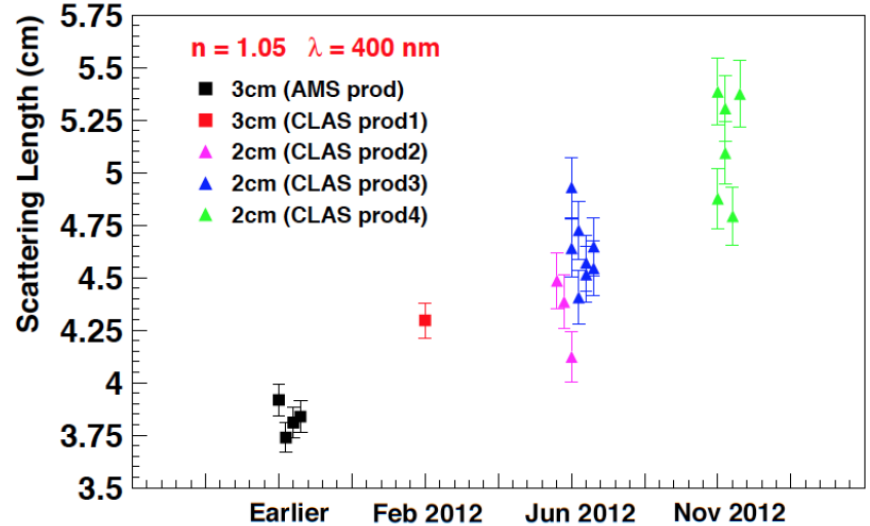
Status of Aerogel Development

Transmittance: $T = e^{-t(1/\Lambda_{abs}+1/\Lambda_{sc})}$

Scattering length: $\Lambda_{sc} = \lambda^4/C$

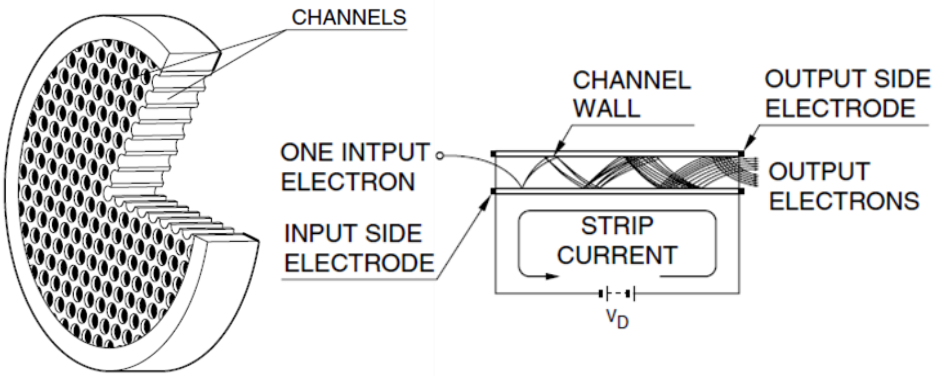


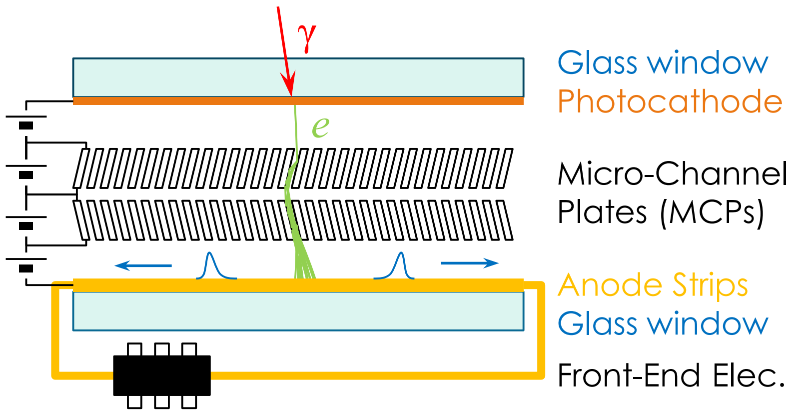
- Aerogel strongly scatters UV lights
- Major manufactures
  - Novosibirsk, Russia
  - Japan Fine Ceramics Center, Japan
  - Aspen, US
- Some comparisons available (CLAS12 etc.)
- Slowly being improved

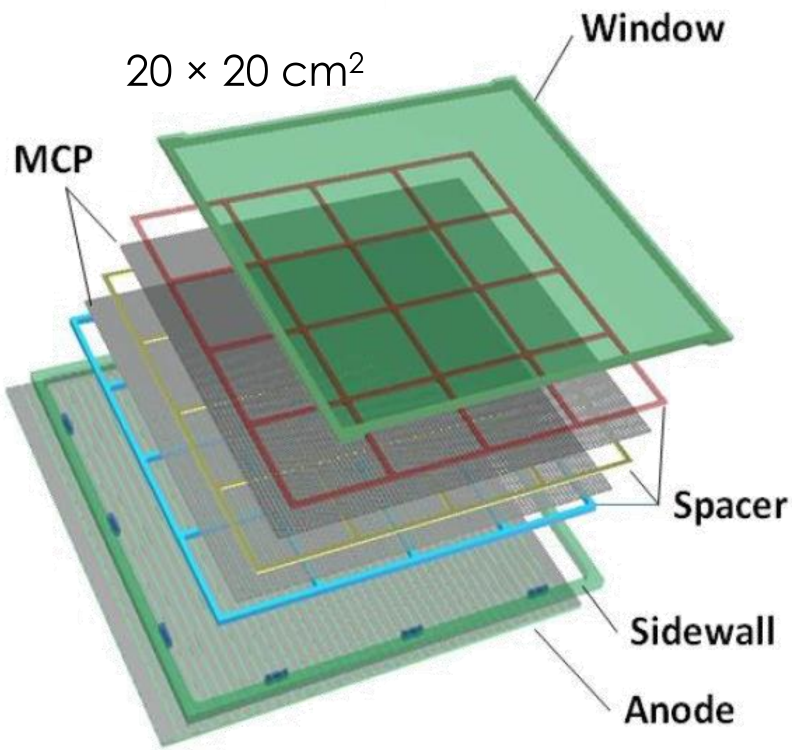


Micro-Channel Plate-based LAPPD

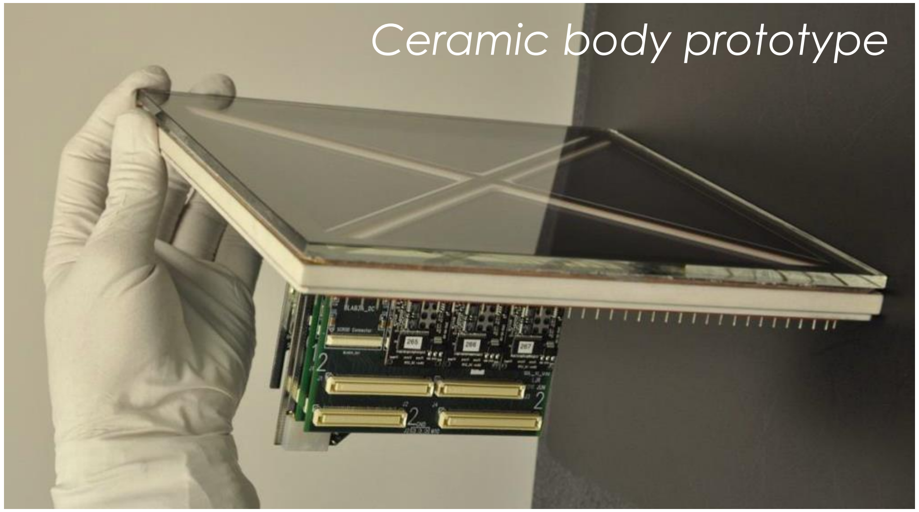
LAPPD: Large Area Picosecond Photo-Detector



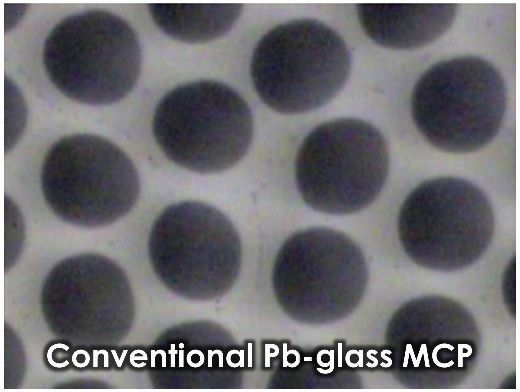




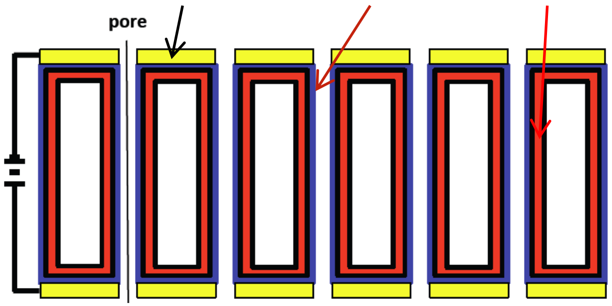
Compact size, good time resolution, expect good tolerance to magnetic field



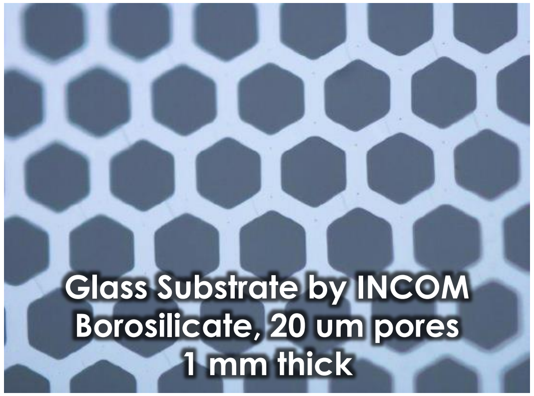
ALD Micro-Channel Plate



- Conventional Pb-glass MCP
  - Single material, three functions: pore, Pb-glass resistive layer, Pb-Oxide emissive layer
  - Higher cost, fragile, limited lifetime

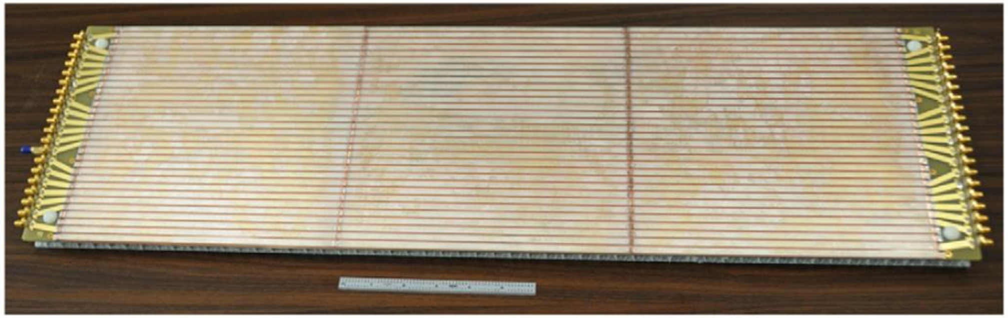


- MCP produced with Atomic Layer Deposition (ALD): more freedom for optimization
  - Glass substrate with pores
  - Tuned resistive layer provides current for electric field
  - Specific emissive layer (Al_2O_3) provides secondary electron emission
- Good performance with lower cost
  - Gain > 10^7 for pair MCPs
  - Longer lifetime >> 5 C/cm^2



LAPPD Readout and Status

- Transmission line readout
  - 5 mm silver strips sampled on both ends with 10 GS/s
  - Lower channel count, can be further chained
  - < 5 mm spatial resolution

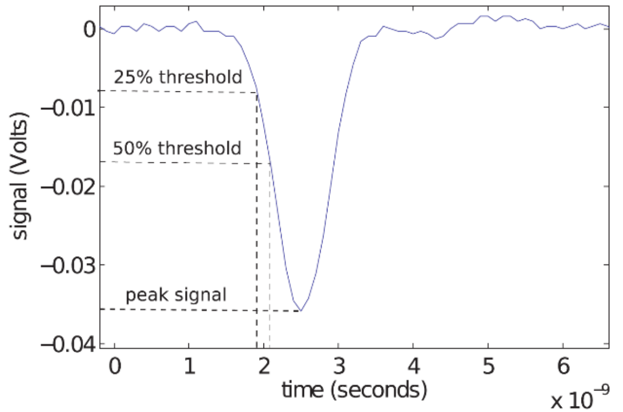


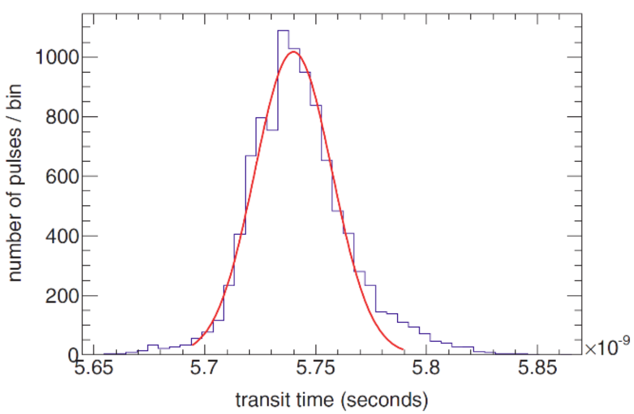
Three 20×20 cm^2 readout board chained

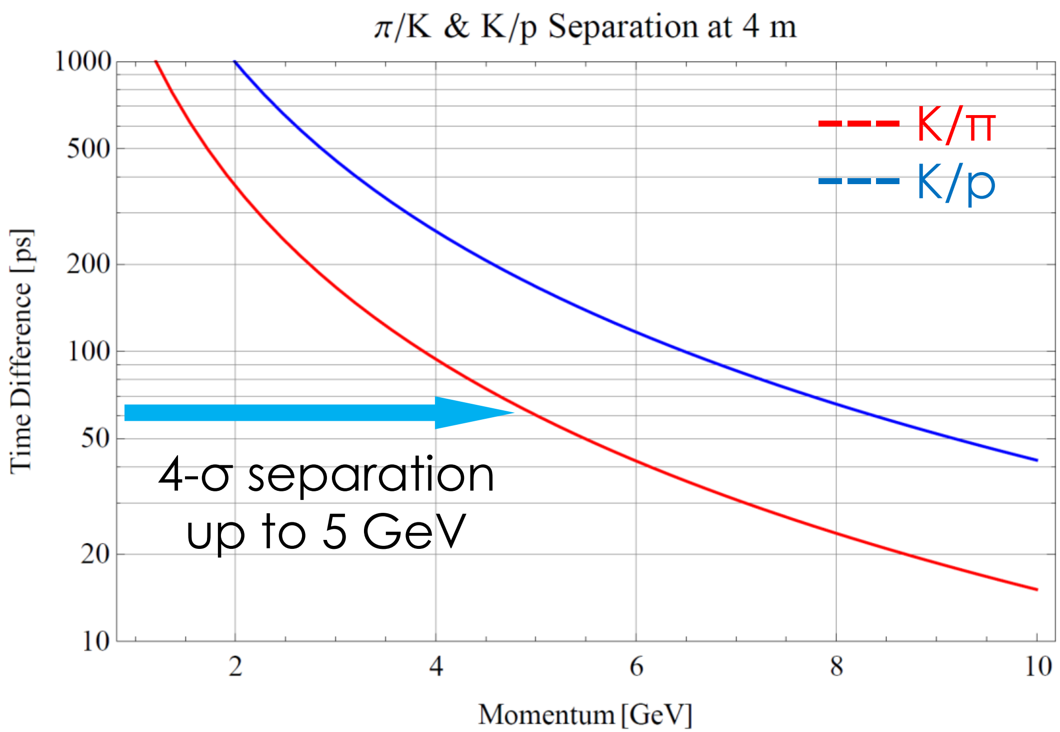
- Status of the LAPPD development
  - Funded by DOE since 2009
  - Individual components proved working
  - A working demountable prototype using Al photocathode
  - First ceramic prototype recently assembled with bi-alkali photocathode
  - Small glass body samples available this year

Bonus TOF feature from LAPPD

- Excellent time resolution of LAPPD provide additional PID power through time-of-flight
  - Use Cherenkov light generated in the entrance window
  - Single photon time resolution < 44 ps



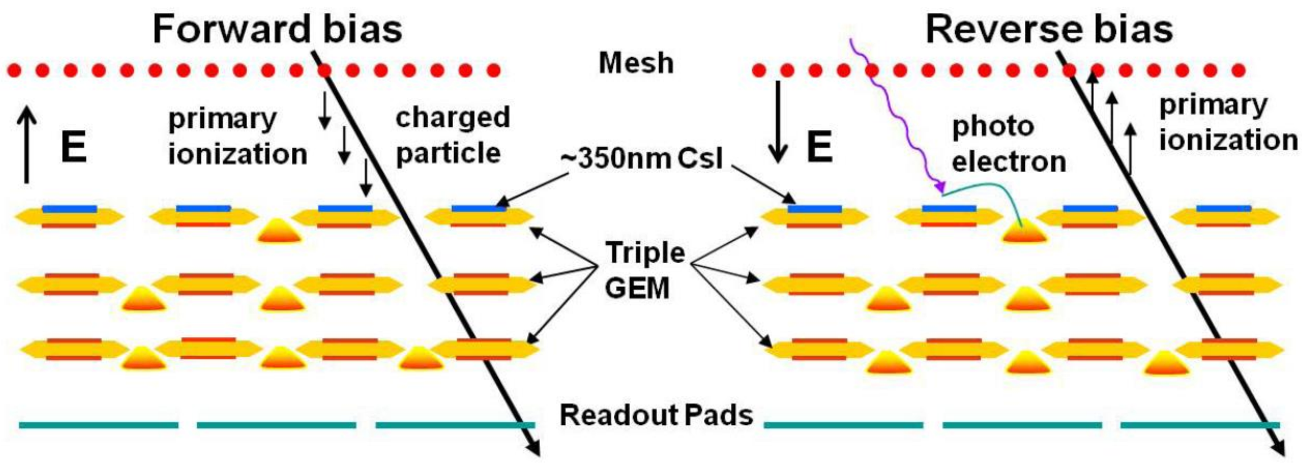


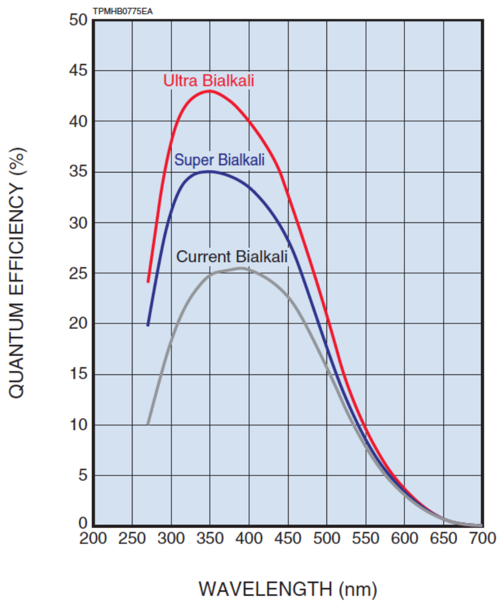


Expected TOF resolution ~ 15 ps

GEM-based Readout

- CsI-coated GEM detector successfully used in PHENIX's hadron blinded-detector (HBD)
  - CsI only sensitive to UV light, not suitable for aerogel
  - Bi-alkali coating possible (Breskin *et al.*), however very sensitive to operating gas
  - Development needed for optimal combination of bi-alkali and gas mixture





Goal of the Proposed Project

- Final goal of the three-year project
  - Determine the optimal detector technology and finish the conceptual design of the RICH detector
- Five parallel tasks
  - Detector simulation and conceptual design (JLab/LANL/BNL)
  - Characterize LAPPDs (JLab)
  - Improvement of LAPPD (ANL/JLab)
  - Study of GEM-based readout (LANL)
  - Characterize aerogel radiators (INFN/JLab/LANL)
- Further prototyping is anticipated given the success of the project

Detector Simulation and Design

- Goals
  - Simulation of detector performance in the EIC environment
  - Provide requirements on detector components, e.g. rate performance, aerogel quality etc.
  - Optimize optics and detector design
  - Determine readout scheme: strip or pixel, maximum size
  - Develop reconstruction software
- Resources
  - Postdoctoral researchers from JLab and LANL
  - Extended from existing EIC simulation codes/event generators

Characterize LAPPDs

- **Goal:** characterize the MCP-based LAPPD with the needs of the EIC
  - Photon detection efficiency
  - Rate capability
  - Time and position resolution
  - Background noise level
  - Neutron and EM radiation hardness
  - Sensitivity to magnetic field
  - Lifetime
- Resources
  - Postdoctoral researcher from JLab
  - Existing testing facilities at JLab
    - PMT test stands, picosecond pulsed laser source, EM and neutron irradiation, 5-T magnet, parasitic electron beam
  - Additional Neutron and proton irradiation facilities at LANL

Improvement of LAPPD

- Goal: improve and balance the performance of LAPPDs towards the needs of the EIC
  - High rate capability
  - Tolerance to magnetic field
  - Thinner glass window (now 2.75 mm) to reduce background hits
  - Optimize existing readout for high multiplicity
  - Alternative readout option if needed
- Resources
  - Postdoctoral researchers from ANL and JLab
  - Existing LAPPD R&D facilities at ANL
    - photocathode coating station, atomic layer deposition station, LAPPD assembling chamber and testing labs

Study of GEM-Based Readout

- Goals
  - Optimize the combination of photocathode coating and gas mixture of a GEM detector to allow detection of photons with wavelength > 300 nm
  - Develop a suitable readout pattern through simulations and bench tests
- Resources
  - Postdoctoral researcher from LANL
  - Expertise in CsI-coated GEM detector
  - LANL will build a small vacuum chamber for bialkali photocathode deposition and quantum-efficiency measurements

Characterize Aerogel Radiator

- Goal: working closely with different vendors, Novosibirsk, Matsushita-Panasonic, Aspen etc. to choose the optimal aerogel tiles for the EIC RICH detector
  - Measurement of transmittance, absorption length and scattering length
  - Measurements of refractive index and chromatic dispersion using the prism method
  - Refractive index mapping with gradient method
  - High precision mapping of the tiles thickness
- Resources:
  - Postdoctoral researcher from Jefferson Lab
  - Clean room at Jefferson Lab
  - Will purchase a spectrophotometer as light source
  - Expertise from INFN, JLab and LANL

Budget

Item	Cost		
	Year 1	Year 2	Year 3
Jefferson Lab			
M&S – LAPPD testing	$10,000	$10,000	$10,000
Equipment – LAPPD testing	$20,000	$0	$0
Labor – Postdoc (0.7 FTE)	$70,000	$70,000	$70,000
Travel	$10,000	$10,000	$10,000
Subtotal	$110,000	$90,000	$90,000
Los Alamos National Lab			
GEM detector kits (5×$3200)	$16,000	$0	$0
CERN RD51 SRS Readout System	$3,000	$0	$0
Components for deposition chamber	$30,000	$20,000	$20,000
Labor – Post doc (0.4 – 0.5 FTE)	$60,000	$80,000	$80,000
M&S and Travel	$20,000	$20,000	$20,000
Subtotal	$129,000	$120,000	$120,000
Argonne National Lab			
M&S – LAPPD fabrication	$15,000	$15,000	$15,000
Labor – LAPPD fabrication and R&D	$50,000	$50,000	$50,000
Travel	$5,000	$5,000	$5,000
Subtotal	$70,000	$70,000	$70,000
INFN			
M&S – Aerogel Testing	$10,000	$10,000	$10,000
Equipment – Aerogel Testing	$30,000	$0	$0
Travel	$10,000	$10,000	$10,000
Subtotal	$50,000	$20,000	$20,000
Grand Total	**$359,000**	**$300,000**	**$300,000**

Summary

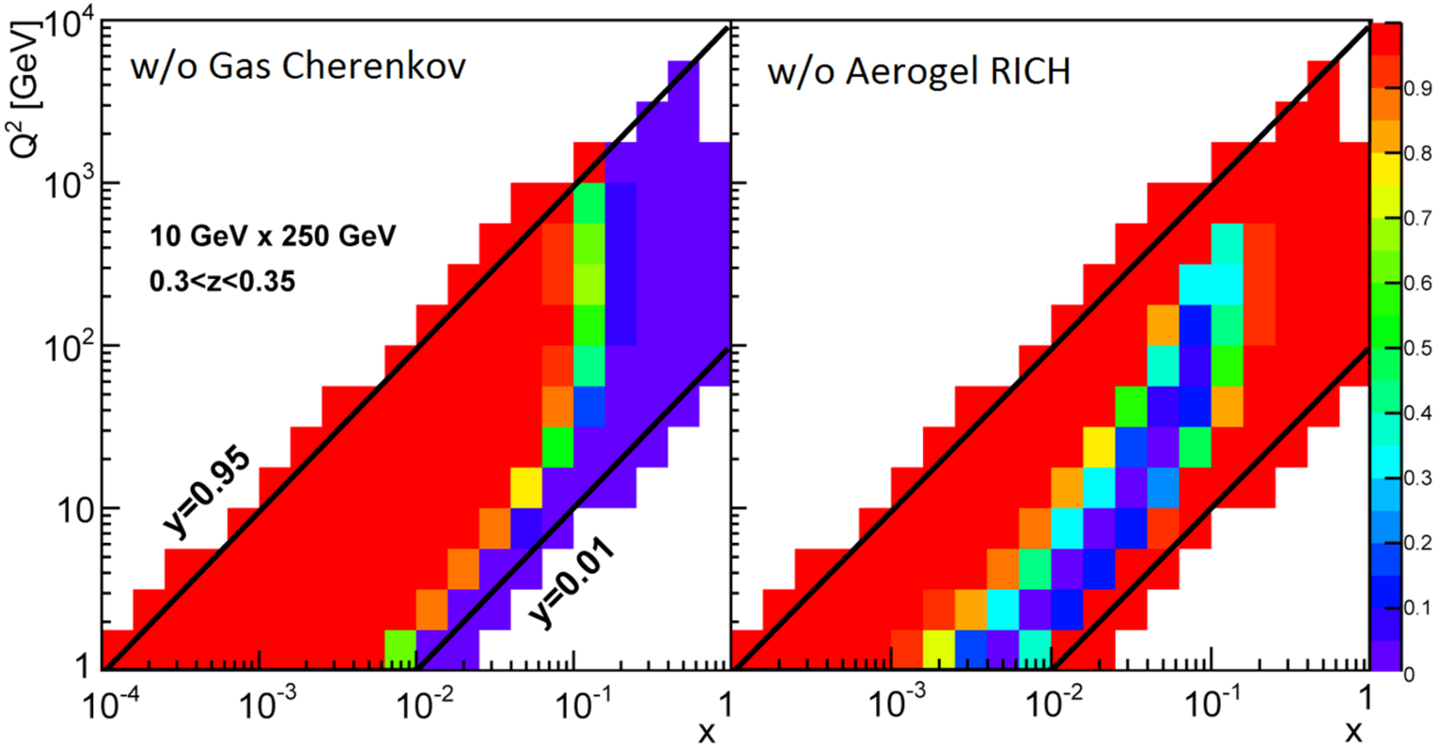
- An aerogel-based RICH detector is proposed to provide necessary hadron identification in the EIC's forward region
- A three-year joint effort is planned to investigate various technologies, find optimal solution and provide a conceptual design for such a detector
  - Two design options will be evaluated: dual-radiator RICH for maximum coverage and modular aerogel RICH for maximum flexibility
  - Two economical novel readout options will be studied: MCP-based LAPPD and GEM-based readout
- The success of the project will become the base of the second phase: development of a proof-of-principle prototype

Backup Slides

Solution to Forward PID

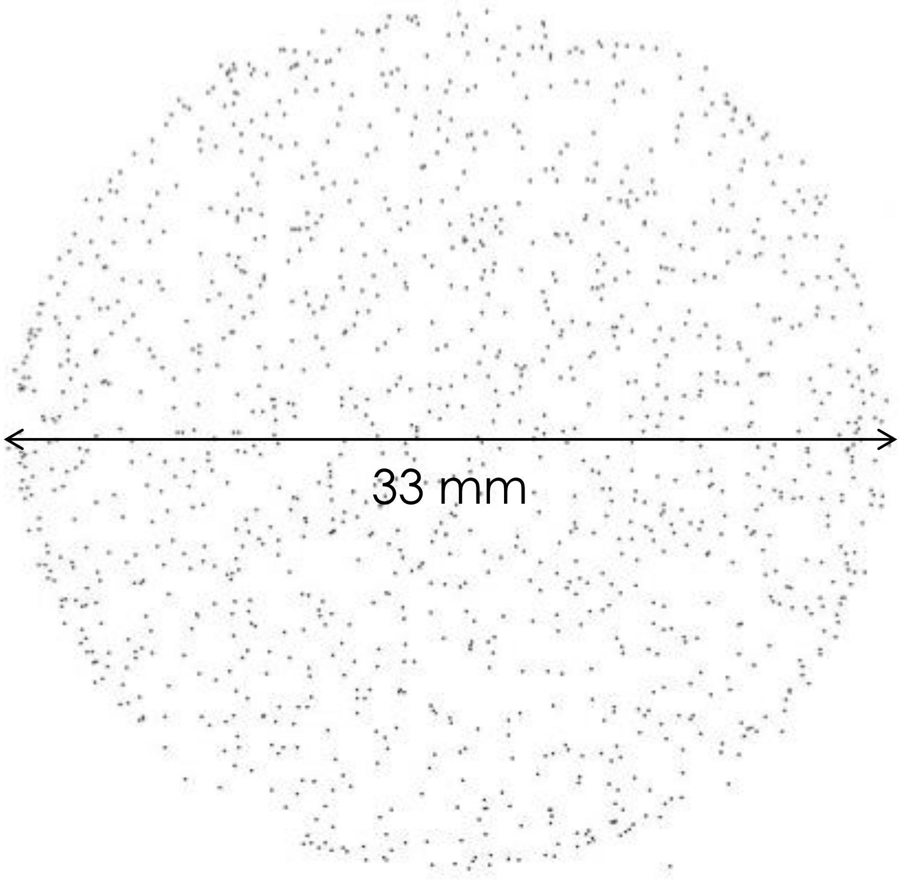
- Multiple radiators are needed to cover the broad kinematic range
  - TOF + high-n radiator (aerogel) + low-n radiator (gas)
  - Can we combine them into one detector?

SIDIS Event Efficiency



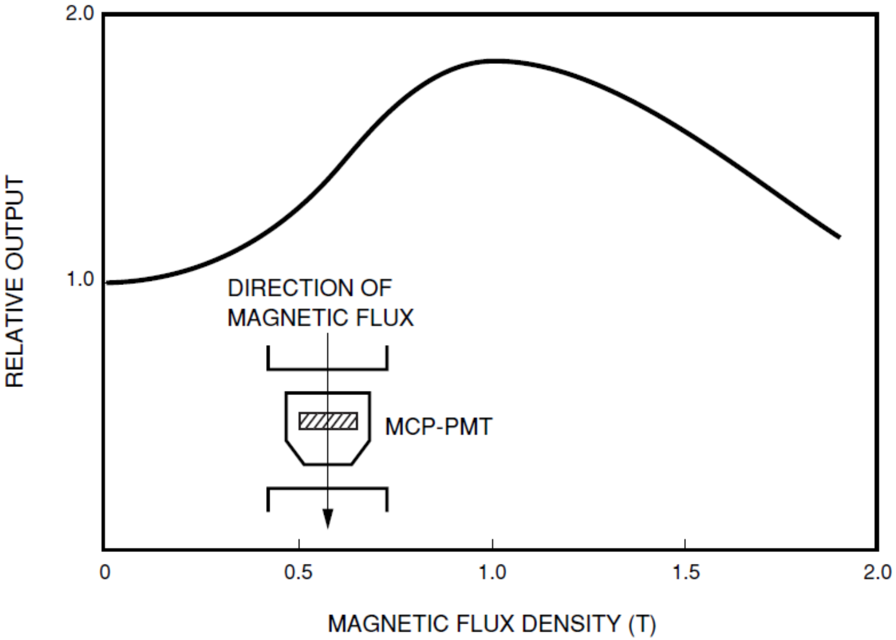
Background rate in ALD-MCP

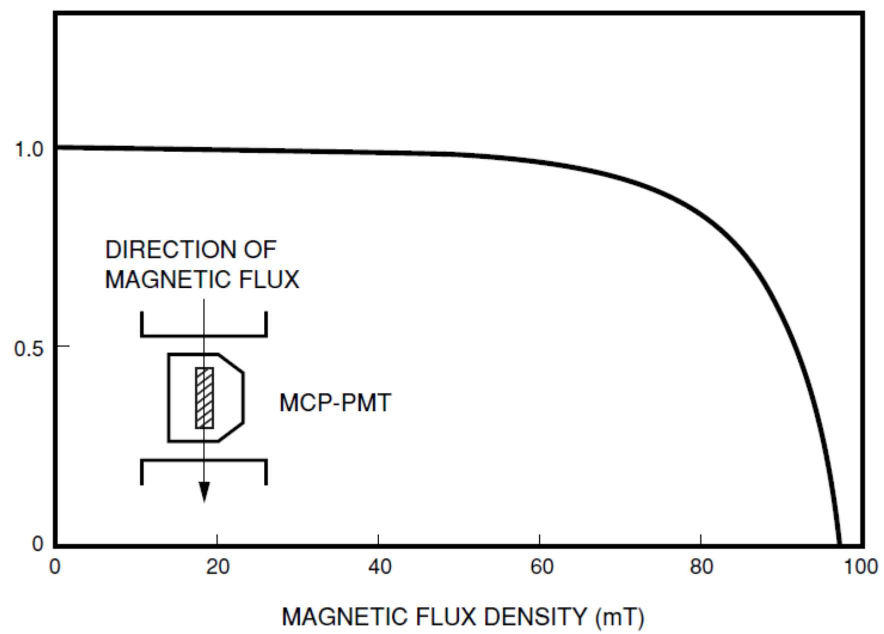
- Background rate of a 33 mm ALD-MCP with 20 μm pores and 1.2 mm thickness measured at 7×10^6 gain
  - 33 mm diameter
  - 20 μm pores, 1.2 mm thickness
  - 0.84 counts/cm²/s, comparable with comic ray
- More test needed for full assembly with photocathode



Background hits over 3000 s

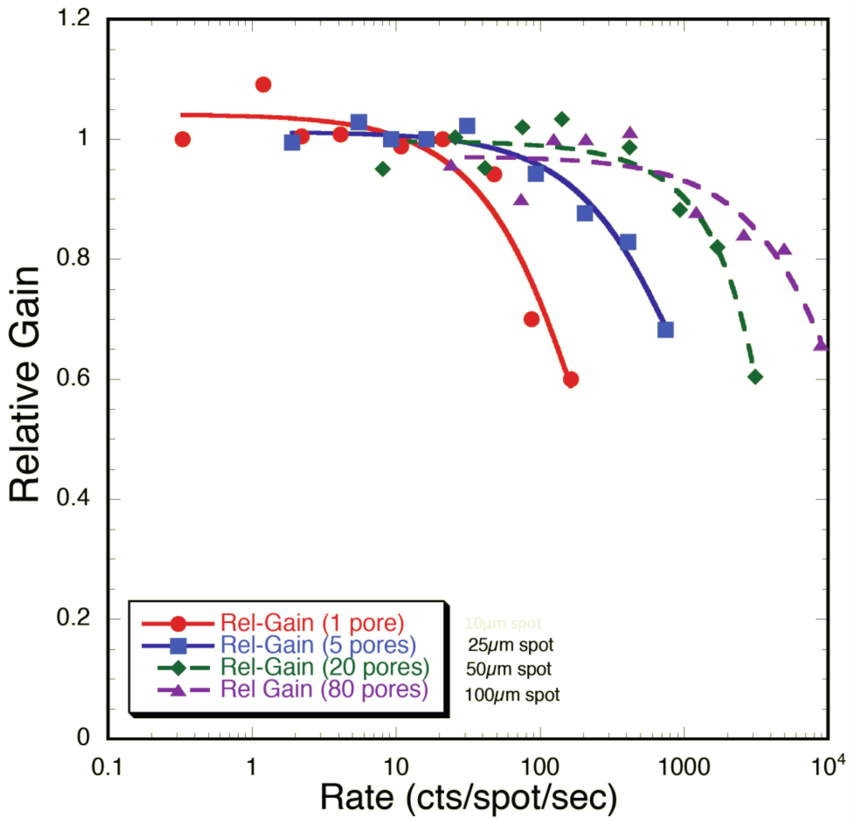
Magnetic Field Tolerance of MCPs



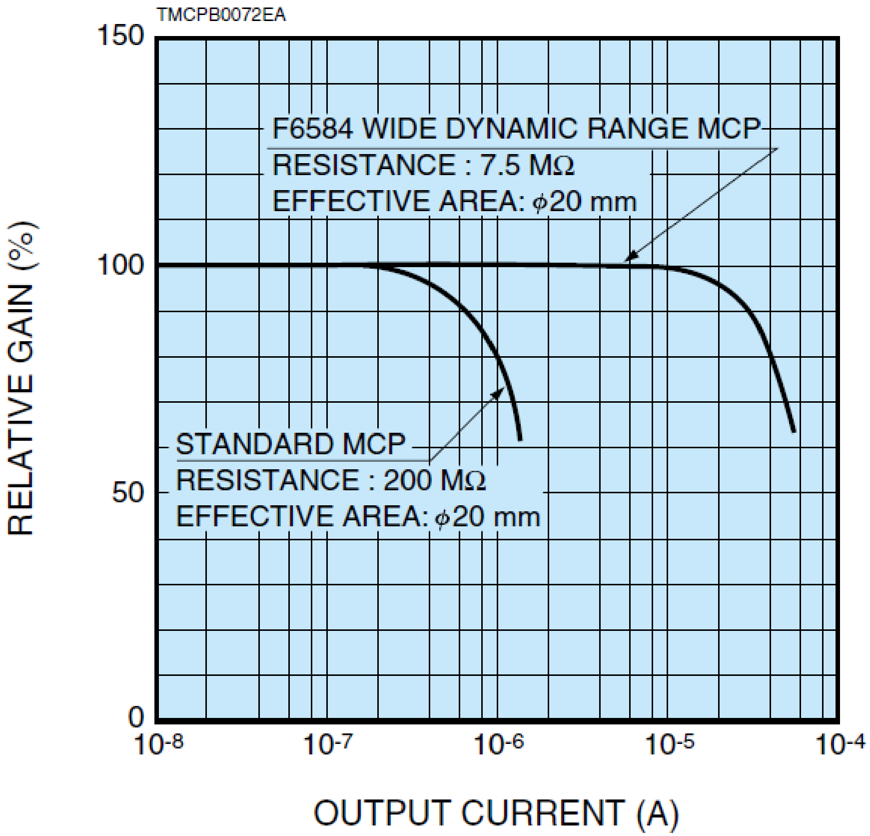


Typical field response of commercial MCPs

Gain of MCP with different rates



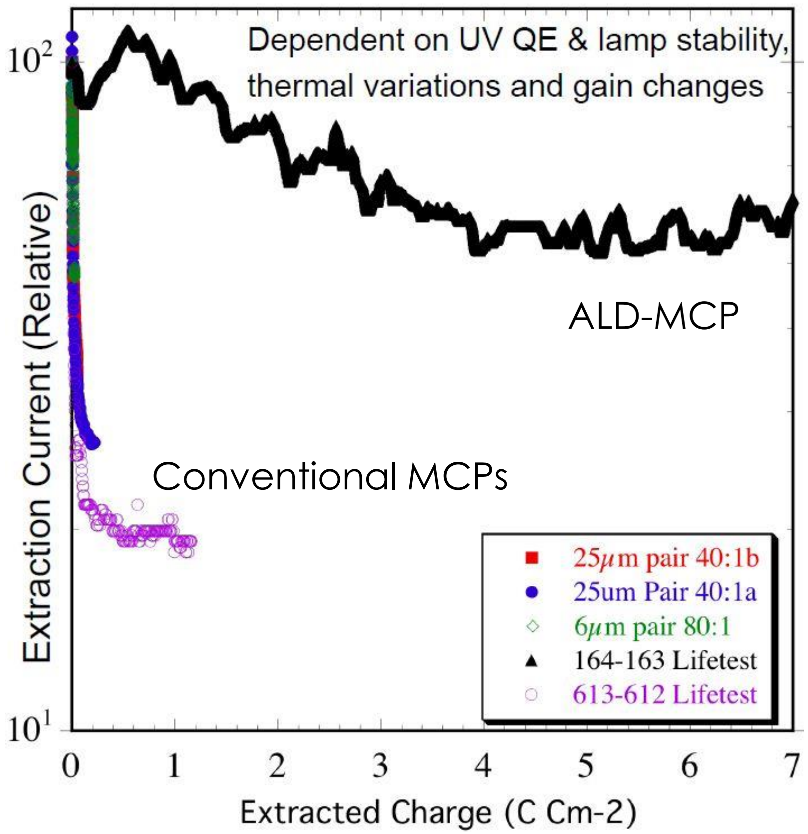
Measurement of an older 10 μm pore ALD-MCP with MgO emission layer



Performance of Hamamatsu MCP-PMTs
10^6 gain → 300 kHz/cm^2

Lifetime of ALD-MCPs

- Significant improvement with preconditioning over traditional MCPs
  - Possibility due to cleaner glass substrate with much less contamination to create ion backflow



Lifetime of an older ALD-MCP pair (20 μm pore, MgO emission layer, 60:1 L/d, 8° bias) compared with conventional MCPs

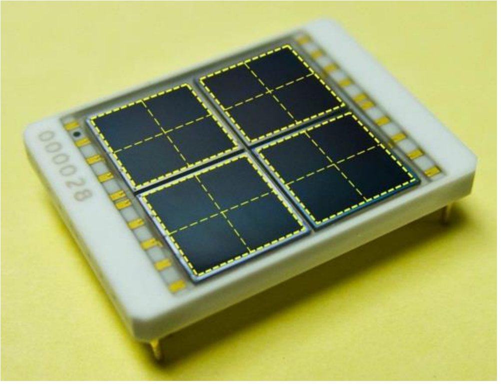
Estimated Final Detector Cost

- Total Coverage ~ 10 m^2
- Dual-radiator RICH using LAPPD ~ $5M
  - Aerogel ~ $1M
  - Gas system ~ $1M
  - LAPPD ~ $1M (MaPMT ~ $10M)
  - Electronics ~ $1M (MaPMT ~ $3.5M)
  - Frame and MISC ~ $1M
- Modular RICH ~ $3M
  - Aerogel ~ $1M
  - GEM ~ $0.6M
  - Electronics ~ $0.6M
  - Frame, Lens and MISC ~ $1M

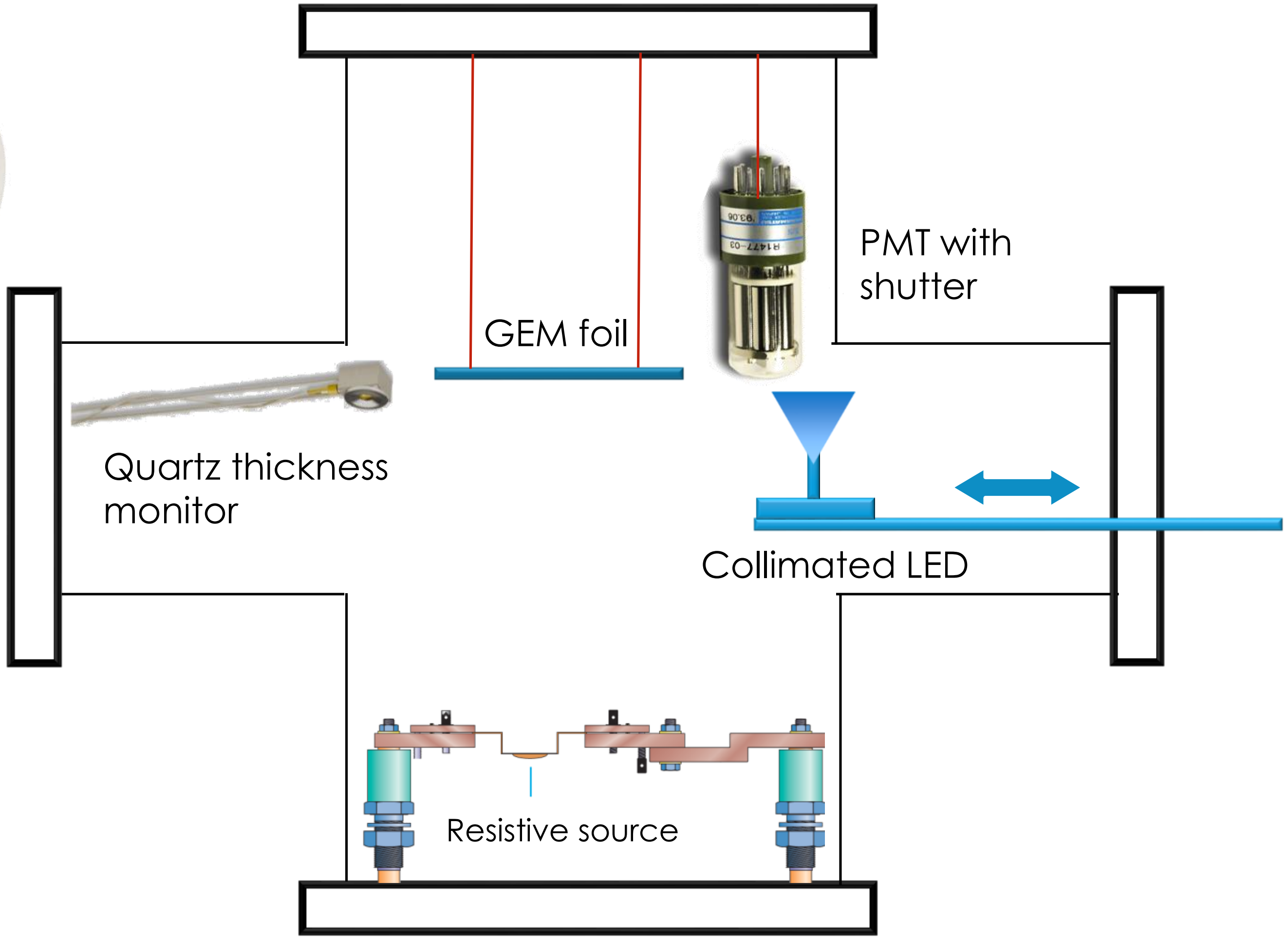
Other Readout Options

- Multi-anode MPTs
  - Well known technology, will be used in CLAS12 RICH and LHCb
  - As small as 3 mm pixel sizes
  - Sensitive to visible light
  - Low noise
  - Moderate resistance to magnetic field
  - Expensive (~$1M for 1 m^2 sensor only)

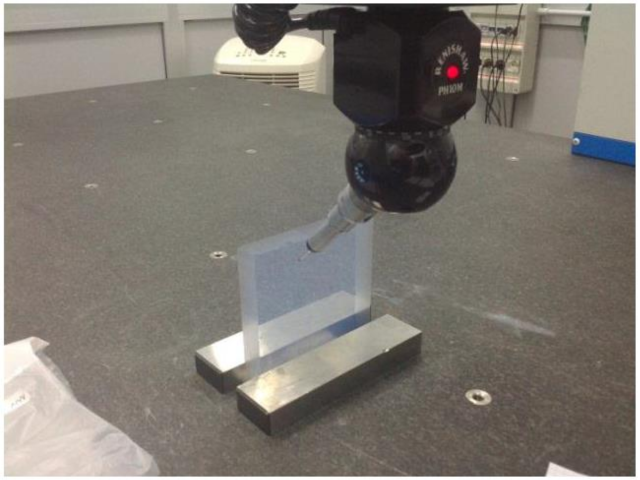
- Silicon Photo-Multipliers
  - Relative new technology
  - 3 mm pixels available
  - Sensitive to visible light
  - Resistant to strong magnetic field
  - High dark rate, needs to be cooled
  - Low neutron radiation tolerance
  - Expensive (~$2 M for 1 m^2 sensor only)



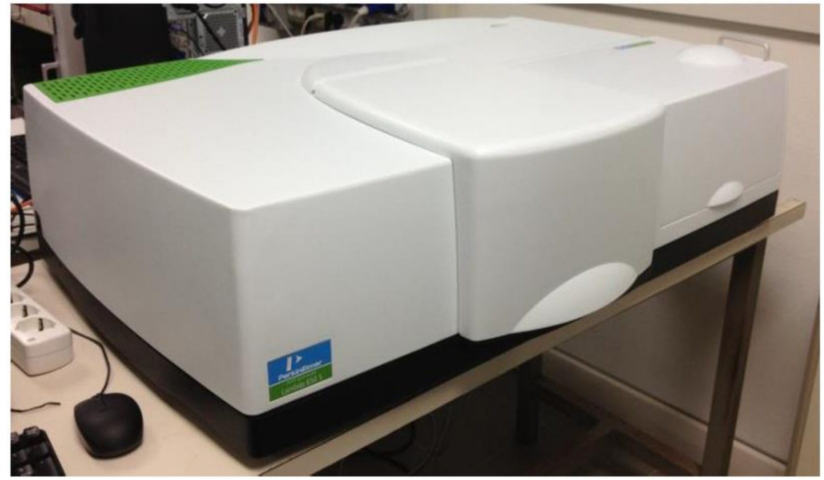
Deposition Chamber/QE measurement



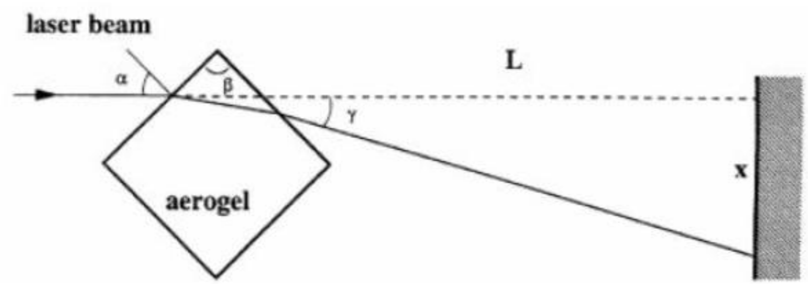
Characterizating Aerogel Tiles



Thickness mapping

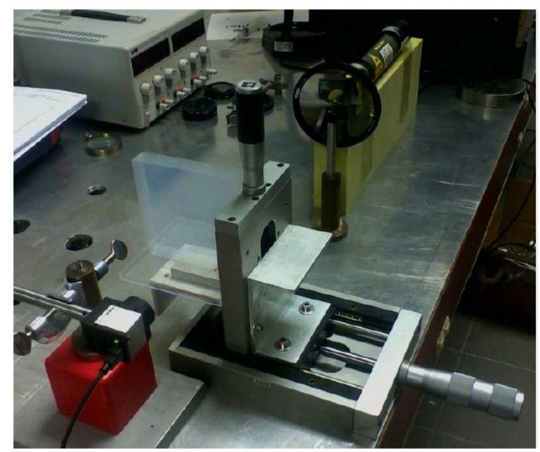


Spectrophotometer as light source



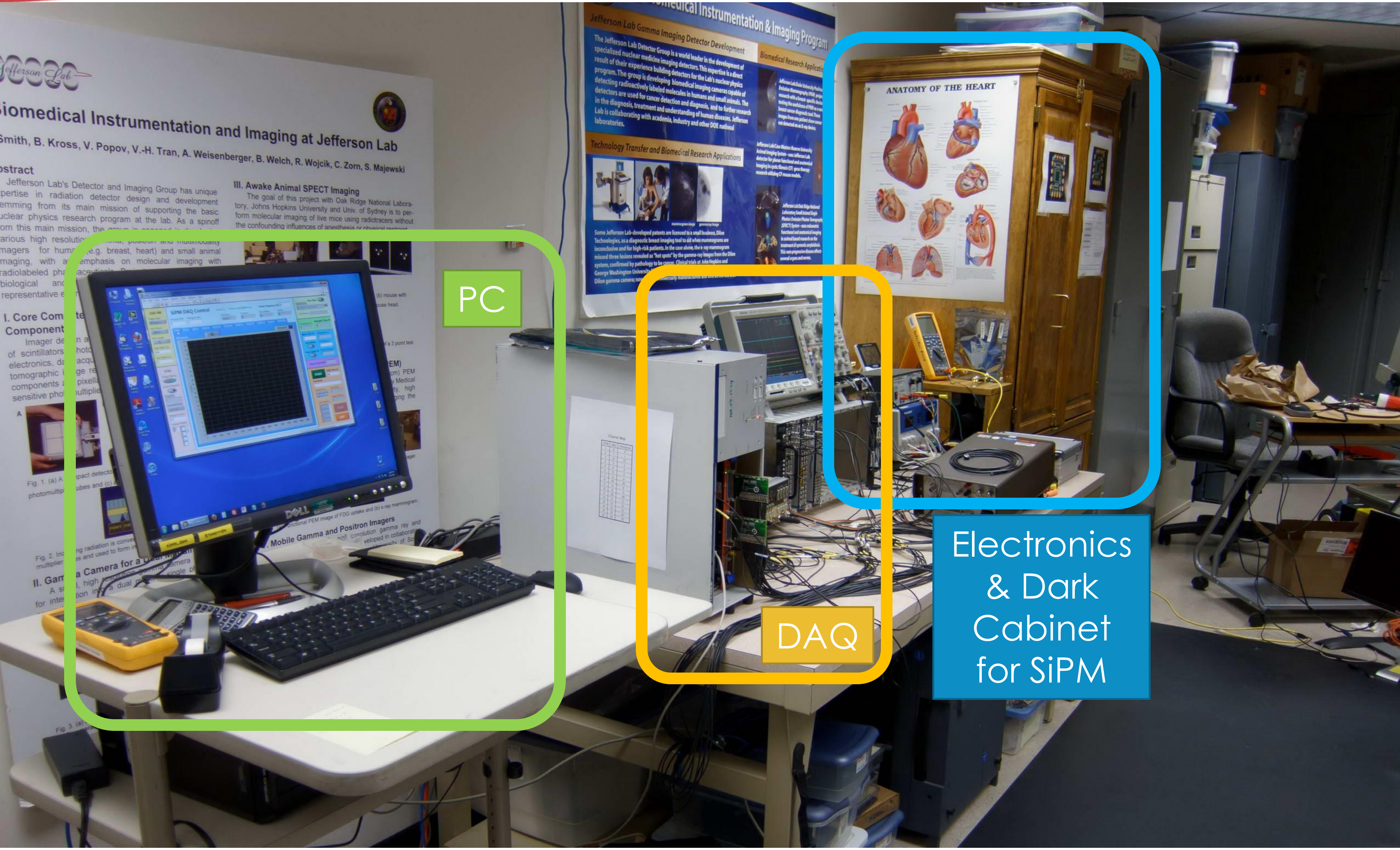
$$\delta = \alpha - \beta + \arcsin\left\{ n \cdot \sin\left[\beta - \arcsin\left(\frac{\sin\alpha}{n} \right) \right] \right\}$$

Prism method for chromatic dispersion



Gradient method for uniformity

SiPM Test Setup

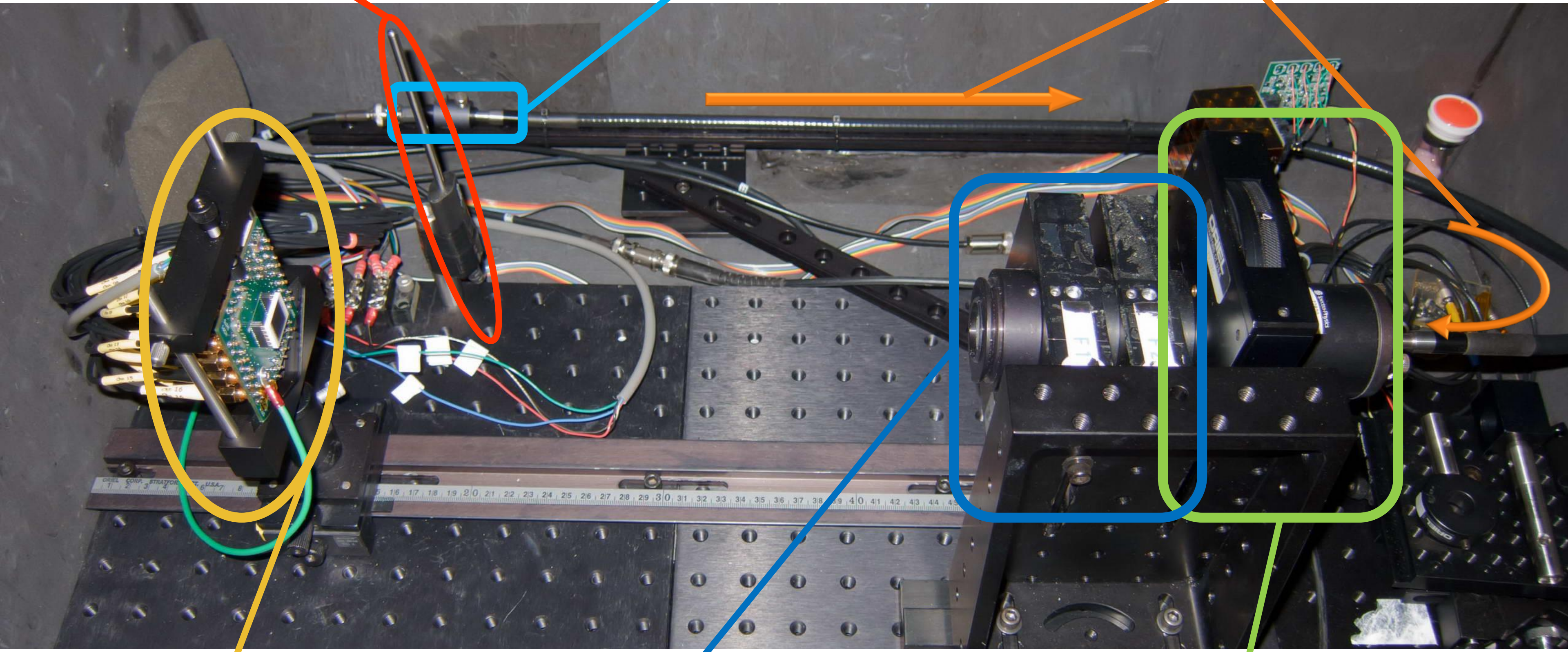


SiPM Test Setup

Temperature Sensor

Blue LED

Liquid Light Guide



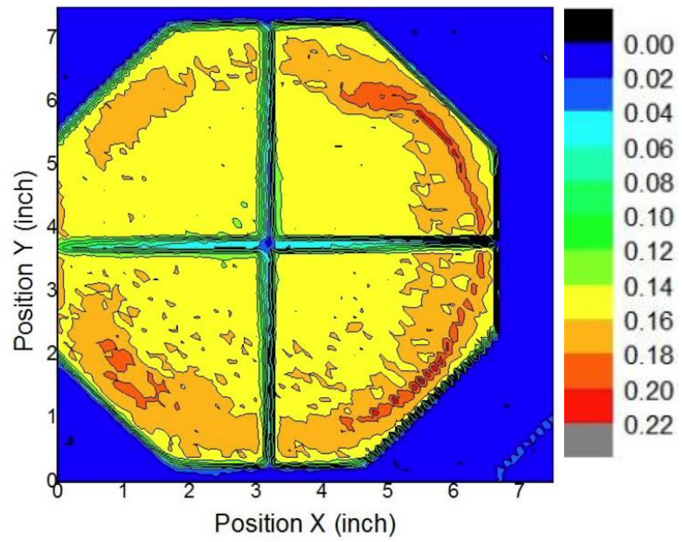
SiPM and Preamplifier

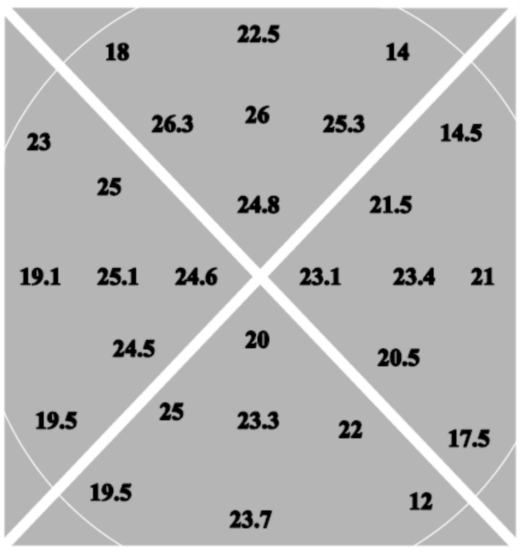
Adjustable Neutral Filter: Dark, 1%, 2%, 4% and 6%

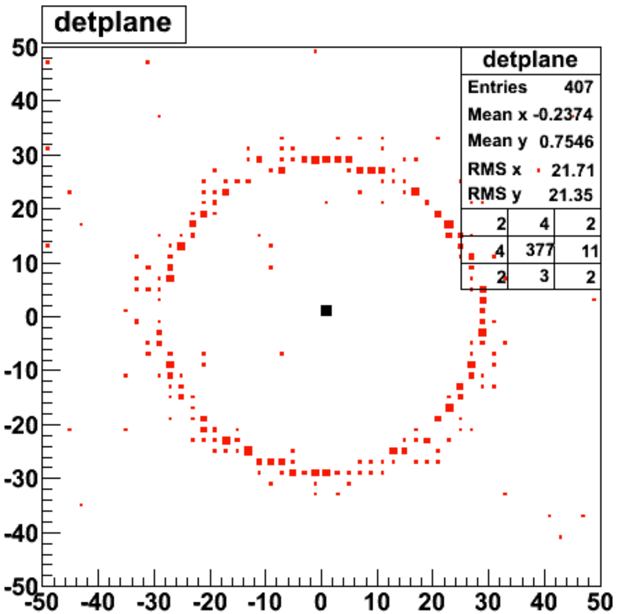
Collimating Lens and 470±10 nm Filter

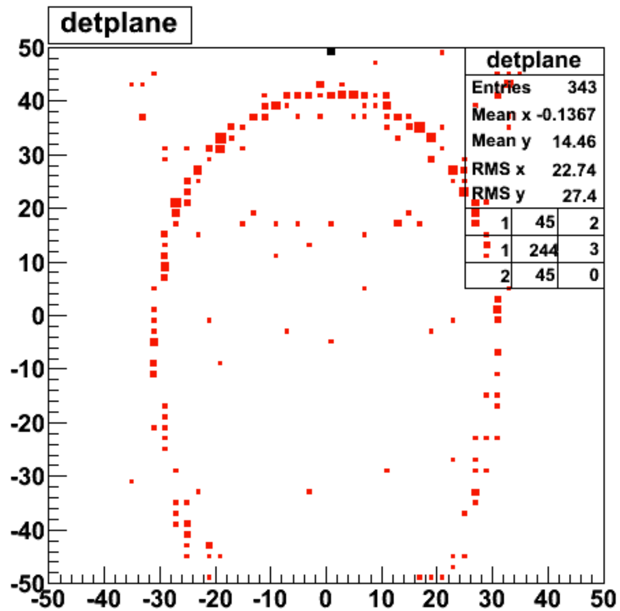
LAPPD's 8" Photocathode

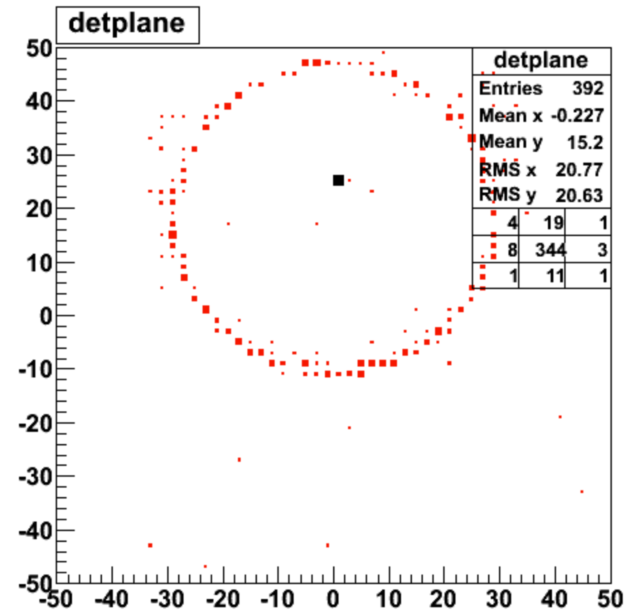
- Argonne National Lab
  - Using Burle PMT processing station with home-made photocathode deposition chamber
  - 7"×7" flat K_2CsSb photocathode was produced
  - Max QE: 22% (350 nm, average: 16%)
- UC Berkeley
  - Deposited Na_2KSb photocathode on 8" windows
  - 25% QE (350nm) with good uniformity (15%) and stability

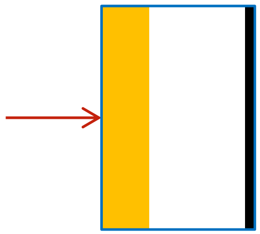




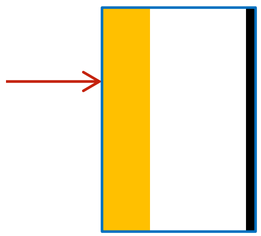




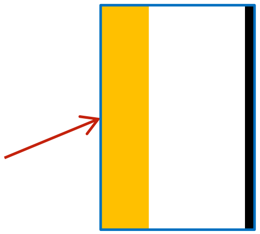




Normal Incident

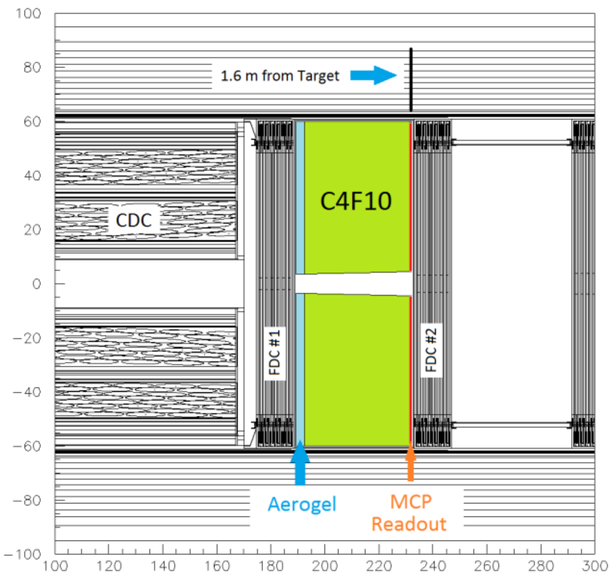


Off-center Incident

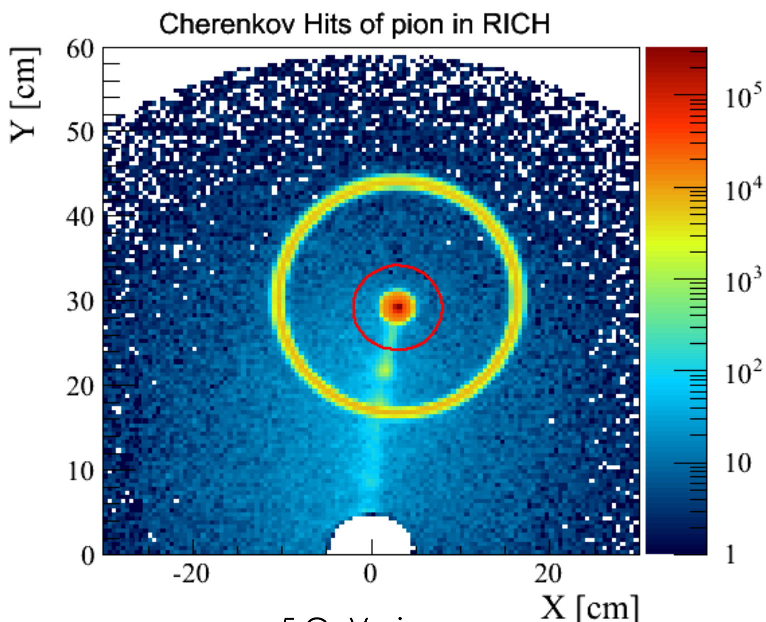


Tilted Incident

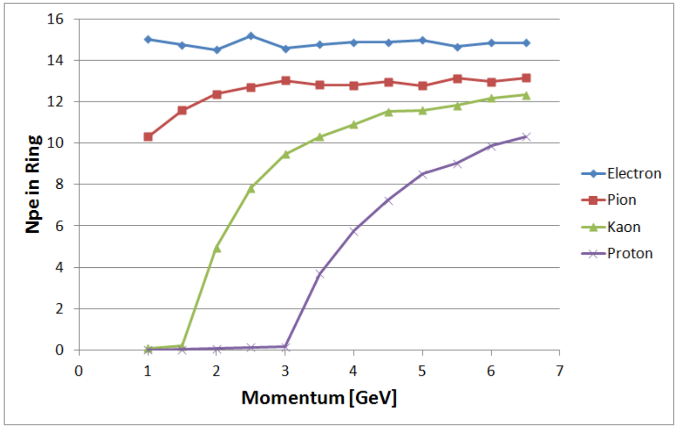
Dual-Radiator RICH Simulation



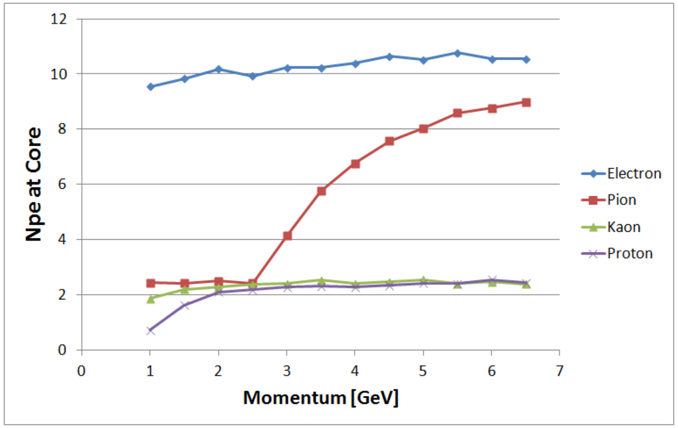
Simulation in GlueX Environment



5 GeV pions



Cherenkov hits from 3 cm aerogel



Cherenkov hits from 40 cm C_4F_{10} and 0.5 mm glass